

The University of Chicago

THE ROLE OF MUSCULAR
TENSIONS IN STYLUS
MAZE LEARNING

A DISSERTATION SUBMITTED TO THE
GRADUATE FACULTY IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

By
JAMES BART STROUD

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

Reprinted from
THE JOURNAL OF EXPERIMENTAL PSYCHOLOGY
Vol. 14. No. 6. 1931

The University of Chicago

THE ROLE OF MUSCULAR
TENSIONS IN STYLUS
MAZE LEARNING

A PART OF THE DISSERTATION SUBMITTED
TO THE GRADUATE FACULTY IN CANDIDACY
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PSYCHOLOGY

By
JAMES BART STROUD

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

Reprinted from
THE JOURNAL OF EXPERIMENTAL PSYCHOLOGY
Vol. 14, No. 6, 1931



THE ROLE OF MUSCULAR TENSIONS IN STYLUS
MAZE LEARNING

THE ROLE OF MUSCULAR TENSIONS IN STYLUS MAZE LEARNING ¹

BY J. B. STROUD

*Kansas State Teachers College
Emporia, Kansas*

INTRODUCTION

It is the aim of this study to investigate the role of muscular tensions in stylus maze learning. This aim embraces an investigation of the problem from three angles: first, a study of the effect of the complexity of the problem, the degree of mastery, and related phenomena upon muscular tensions as normally expressed by the subjects; second, a study of the relation of muscular tensions to the speed of learning; third, a study of the effect of artificially inducing such tensions upon the speed of learning. It is a common observation that a tensing of certain muscle groups occurs in preparation for and during important and vigorous experiences of many kinds ranging all the way from colorful emotion to ordinary experiences such as climbing a flight of stairs hurriedly. In a dental chair one may catch himself pushing against the foot rest or gripping the arms of the chair with great force during a crucial part of the experience. During examinations one may observe students massaging their hands and fingers made numb from gripping their pencils or even observe the tension of facial muscles. Bills (1) has shown that such concomitant muscular tension serve a beneficial purpose in memorizing and in doing mental work. His investigation centered upon the effect of voluntarily induced muscular tensions upon these mental processes. The present study extends the investigation to problem situations such as that presented in the maze and to two other aspects of the general problem, namely, the effect of the difficulty of the problem, progress in learning, etc.,

¹ From the psychological laboratory of the University of Chicago.

The writer gratefully acknowledges the assistance of Professor A. G. Bills in every phase of this research.

upon the natural expression of muscular tensions and the relation of such tensions to the speed of learning. It does not necessarily follow that because induced tension facilitates rote memorizing and mental work it would also facilitate learning of the type involved in the stylus maze problem, or that it would facilitate it to the same degree. This investigation is also concerned, then, with the study of the role of muscular tensions in motor learning, as contrasted with ideational learning such as memorizing.

Another factor which led to the selection of the maze as the learning material for this study was the fact that it seemed possible to construct a stylus which would give a serviceable measure of muscle tension of the subjects while solving the problem. Furthermore it seemed possible to vary the difficulty of the parts of the maze so as to observe the effect of varying degrees of difficulty of the task upon the expression of muscular tension. A maze has certain other advantages for a study of this kind. It constitutes a problem whose difficulty varies from time to time, even with the same subject. The subject may become confused and 'lost' during any given trial and have considerable difficulty in getting around to the terminus. A knowledge of any changes in muscular tension which might take place during such trials would throw significant light upon the nature of the adaptive processes.

Considerable experimentation has been made, either directly or indirectly, upon the phenomena of muscular tensions in relation to mental activity.² Some of the studies bearing more directly upon this problem are cited below.

Bills (1) in his study raised the question of whether these concomitant motor expressions are merely an overflow phenomenon of some kind or whether they are of some value *per se* to the individual. As a result of his investigations in which he induced muscular tensions artificially he concluded that they are of value in and of themselves. He induced tension by having his subjects squeeze spring dynamometers, one in each hand. He found these exercises directly beneficial in learning nonsense syllables and paired associates, and in

² Bills has adequately reviewed the pertinent literature in his study cited above.

adding columns of digits and in recitation of scrambled letters. In the addition and recitation experiments he found that induced tension had the effect of lessening the work decrement. Induced tension had the effect of decreasing errors as well as increasing speed.

Miller (11) has shown that the experience of pain and the observable response consequent upon the receipt of electrical shocks may be diminished by 'progressive relaxation.' She had her subjects immerse the tips of their fingers in a salt solution through which an electrical current could be passed. The height of the jerk of the hand could be measured. Her subjects had had three months training in 'progressive relaxation.' Frequently one of her subjects would fall asleep in his relaxed state. The reaction of the subjects during sleep was quite similar to that during the relaxed state.

Jacobson (6) states that mental activity can be greatly diminished by 'progressive relaxation' and that when such relaxation is complete the subject is quite apt to fall asleep. His subjects report a dearth of mental imagery during the relaxation of the eye muscles. In another study reported by him (7) Jacobson seems to have obtained rather clear evidence that effort to attend is accompanied with motor tensions and that inattention and effortlessness are associated with relaxation.

The height of the knee jerk has usually been taken as a good index of muscular tension. Voluntary tensing of any of the muscles of the body increases the height of the knee jerk. Tuttle (14) has shown that the height of the jerk may be materially increased by arithmetic work over that of a passive attitude and that the height is greater during an ordinary period of conversation than during a passive period. Lombard (10) pointed out as early as 1886 that an increase in the height of the knee jerk may be effected by irritation of the skin, by voluntary movements such as swallowing, talking, and clenching of the hands, and by exciting the attention. He also pointed out that the jerk may be facilitated by cerebral activity and decreased by cerebral inactivity and sleep.

Morgan (12) has shown that in typewriting situations the

subjects have a tendency to strike the keys harder during distractions. Laird (9) has shown in an experiment with typists that the amount of expired carbon dioxide is enormously increased over the normal by introducing distractors. These experiments point to a close relationship between such physiological processes and a factor called effort.

APPARATUS

The apparatus used in this experiment has been described in a note entitled *Apparatus for Recording Muscular Tensions*, recently accepted for publication by this *Journal*. It consists primarily in a pressure stylus with a piston device for recording downward pressure and a pneumatic attachment for recording the squeeze or horizontal pressure. Incidentally a record of jaw tension was secured by training spring tambours upon the jaw muscles. A record of the muscular tensions exerted upon the pressure apparatus was made upon a kymographic drum. In these experiments tension values are reported for downward pressure only.

DETAILED PLAN OF THE EXPERIMENT

The investigation is divided into three main parts. Part I is given over to the study of the factors which influence the expression of tension. An attempt is made to see if the degree of tension varies with the difficulty of the various parts of the maze and to see if it varies from maze to maze when such mazes are of different degrees of difficulty and to ascertain what direction the variation takes. It is the aim of this part of the study to see if tension varies with the degree of familiarity with the mazes and to see if it varies during the initial and final stages of the learning process. An attempt is also made to see if the tension expressed during the trials in which the greatest number of errors is made—trials in which the subject has the greatest difficulty, differs from that expressed during the trials in which the least number of errors is made, and to see what direction the variation takes, if any. Part II is taken up with the relation of tension to the speed of learning. The aim of this part of the study is to determine whether there

is any relation between the degree and constancy of muscle tensions as expressed naturally by the subjects and the speed with which they solve problems of the kind presented in stylus mazes, and to determine what the relation is. Part III deals with the effect of induced tension upon the speed of learning. The experiment described therein is designed to determine the effect of inducing muscle tensions artificially upon the speed of learning.

PART I. FACTORS WHICH INFLUENCE THE EXPRESSION OF MUSCULAR TENSIONS

(a) *Tension in an Easy Part of a Maze Versus That in a Difficult Part.*—Easy parts (parts without cul de sacs) constitute the first and last fourths of maze CIV. An electric marker indicated upon the drum the point at which the end of the first 'easy' portion had been reached for each trial; and in a similar way it indicated the point at which the subject entered upon the final 'easy' portion in his tracing. By taking the average tension for each of the 'easy' portions and comparing this with the tension expressed during the tracing over a similar period of time in the adjacent difficult portion the effect of degrees of difficulty upon the expression of muscle tensions could be determined. Twelve graduate students in psychology were used as subjects in this experiment. The results are found in Table I.

(b) *Tension on an Easy Maze Versus That on a Difficult Maze.*—In this experiment the tension expressed during the mastery of an easy maze is compared with that expressed during the mastery of a difficult maze. Sixteen subjects participated in this experiment. All the subjects were undergraduates with little training in psychology. Each subject learned both mazes, 24 hours elapsing between the two tasks. A counterbalanced order was used. While mazes III and IV were not purposely selected in such a way as to fit into this experiment, it happened that considerable difference in difficulty was found between them. The tension comparisons obtained from the data for these two mazes are also included in the results. The time, trials and errors required to learn the mazes constitute the criteria of difficulty.

(c) *Tension on Trials with the Greatest Number of Errors Versus Tension on Trials with the Least Number of Errors.*—The average tension for the three trials with the greatest number of errors is compared with that for the three trials with the fewest errors. Only trials from the first half of each record were considered. Data gathered from the studies made with mazes CIII, CIV, and III were used in making these computations. The data from maze CII were treated in a similar way save for the fact that the average tension for the two trials out of the first six with the greatest number of errors is compared with the average tension for the two trials out of the first six with the fewest errors. From maze CIII two consecutive trials from each record were selected for comparative purposes in which there was a difference of 10 or more in errors between the two trials and in which case the trial with the fewest errors came first. The first and second pairs of trials meeting this requirement which occurred in each record were selected. The varied attack upon this problem was made in an effort to control the influence which changes in tension with progress in learning might have upon these results.

(d) *Changes in Tension During Progress in Learning.*—The average tension is computed for four different stages of three trials each. The first three trials, the middle three, the last three and the three immediately preceding them were chosen for this purpose. Since the criterion of learning was three consecutive correct trials it seemed that a separate tabulation of the last three trials might yield significant results. By this procedure it is possible to observe the changes in tension and variability which occur over these four stages and to study the effect of increasing familiarity with the problem upon the expression of muscular tension. The results of these computations are found in Table IV.

(e) *Initial Changes in Tension.*—Three different observations are made upon this problem. Comparisons are made of the average tension of each of the first three trials of mazes CII and CIII. Secondly, a study is made of the changes in tension which occur during the first minute of tracing each of

these mazes. In this part of the study tension is averaged for 10 second intervals, making it possible to make six different comparisons within the minute period. A similar study is made of the changes in tension during the first minute of four trials each for 24 subjects selected at random from all the mazes. The results are contained in Table V.

(f) *Final Changes in Tension.*—This phenomenon was investigated by examining all the records for three mazes, CII, CIII, and III. The tension and time values for each of the last three trials were computed. The average tension for each of the last three trials taken separately was computed and the values compared with one another. Time values are offered as an aid in interpretation. The average tension for the last three trials taken together is compared with that for the three preceding trials. (See Table IV.)

PART II. RELATION OF TENSION (NATURALLY EXPRESSED) TO THE SPEED OF LEARNING

The criteria of speed of learning are scores in time, trials and errors, each computed separately. No special experiments were made to test this relationship. The data obtained for all the mazes were used in making these calculations.

PART III. THE INFLUENCE OF ARTIFICIALLY INDUCED TENSION UPON THE SPEED OF LEARNING

Thirty-two subjects were used in this experiment, 15 of whom were undergraduate students with no prior experience with mazes; 17 were graduate students with varying degrees of sophistication. Each subject learned two mazes, III and IV. One maze was learned by each subject under the influence of induced tension, the other was learned under normal conditions. The counterbalanced order was used both as to temporal order of the mazes and as to tension. Tension was artificially induced in this experiment by having the subjects hold a weight against a pulley while tracing the mazes. The weight exerted a static pull of 14 pounds. The subject held the weight in one hand. The cord to which the weight was attached pulled at right angles to the body and was on a level

with the maze. The subject sat erect. This procedure necessarily produced considerable tenseness in several muscle groups as well as in the hand, arm and shoulder muscles. The subject had to brace himself in order to prevent being pulled over or to one side by the weight. Hence, in order to maintain his postural attitude the subject had to tense various back and leg muscles. In order to obviate the possibility of fatigue and a consequent change in experimental attitude on the part of the subjects resulting from protracted holding of the weight they were informed that they could rest from the load between trials if they grew tired. Since the subjects differed considerably in this respect (some subjects required no rest at all) this procedure seemed preferable to rest at stated intervals. Occasional pauses were introduced in the condition in which no weight was held. This was done in order to make the two conditions somewhat comparable with respect to the condition of pauses interpolated during the learning.

The usual tension records were taken throughout this experiment. It was possible to observe the effect of induced tension not only upon the speed of learning, but also upon the tension expressed in the hand operating the stylus. It was also possible to observe the effects of induced tension upon the constancy of the tension expressed throughout the stages of the learning process. These phenomena are studied by comparing the tension data obtained for the condition of induced tension with the data obtained for normal conditions. The several effects of induced tension are recorded in Tables XI-XIII.

It seemed possible that some significance might be attached to the variability of the tension curves. Variability was computed by subtracting the length of the base line for a given trial from the total distance traversed during that trial by the pen recording tension. The measure of variability is the length of the curve minus the length of the base line. If for a given trial the length of the tension line is 15 inches and that of the base line is six inches there are nine inches of excessive distance because of the crookedness or variability of the line. The greater the difference between the length of the base line and the tension line the greater is the variability.

RESULTS AND DISCUSSION

Part I. Factors Which Influence the Expression of Tension

(a) *Relation of Tension to the Difficulty of the Portions of the Maze.*—The table below gives the average vertical hand tension of all subjects and all trials for the two intervals in which all the 'cul de sacs' were blocked off and that for the two adjacent sections involving the same length of time. Maze CIV was used for this purpose.

TABLE I
SHOWING THE RELATION OF TENSION TO THE DIFFICULTY OF THE MAZE

Average tension for initial 'easy' section of the maze.	Average tension for adjacent difficult section of the maze.
.21 inches	.32 inches
Average tension for final 'easy' section of the maze.	
.39 inches	.32 inches

While these data are significant they fail to contribute a great deal to the purpose for which this experiment was planned. The average tension for the initial 'easy' section is significantly less than that for the subsequent difficult section. But this same phenomenon, as shown in Table VI, is present in all the records. There is a period at the beginning of each trial in which a muscular set is being assumed in which one finds just such a phenomenon as that presented above. One is not warranted in assuming that these data show any relation between tension and the difficulty of the portions of the maze. On the other hand they fail to show that there is no such relation.³ It will also be observed from the table above that the data comparing the tension for the final 'easy' section with that of the adjacent difficult section show that the tension is significantly greater during the easy period than for a similar difficult period. It seems improbable that this represents a true relation. It seems more

³ A more valid procedure could have been carried out by arranging the 'easy' portion in the center of the maze. Unfortunately almost a year has been consumed in working up the data from the kymographic drum records. Some problems have arisen which were not anticipated at the time the experiments were made. The experimenter does not now have access to the apparatus so that some of these suggestions can be investigated.

likely that this difference is an expression of an end-spurt phenomenon and that if there should be any changes in tension during the tracing of this section of the maze because of its easiness such changes are obscured by this phenomenon which we may call end spurt.

(b) *The Relation Between Tension and the Difficulty of the Maze.*—It will be recalled that mazes CII and CIII were selected specifically for this purpose. It developed that sufficient difference in difficulty obtained between mazes III and IV to warrant using their data in studying the relation between tension and the difficulty of the maze. The differences in difficulty may be seen by inspecting the time, trial, and error scores for these mazes in the following table. The same subjects learned CII and CIII, and III and IV.

TABLE II
SHOWING THE RELATION BETWEEN TENSION AND THE DIFFICULTY OF THE VARIOUS
MAZES

Maze	Average Tension	Average Seconds	Average Errors	Average Trials
CII	.302 inch.....	354	20.7	10.3
CIII	.204 inch.....	2671	424	44.9
CIV	.315 inch.....	2043	246	26.9
IV	.335 inch.....	563	82	14.
III	.318 inch.....	1543	221	29.8

Taken at their face value these results seem to indicate that there is an inverse relation between tension and the difficulty of the task. Upon further examination of the data one finds that these differences are due entirely to the fact that there is a drop in tension on the more difficult mazes as learning progresses and that there is a rise in tension on the easy mazes with subsequent trials. This is readily seen from Table IV, where the tension values for the different mazes are averaged separately for four different stages in learning. The increase in tension with progress in learning the easier mazes may be due to a factor of spurt which the subjects exhibit when they discover they are on an easy maze. This suggestion derives experimental support from recent studies by Bills and Brown (2). They found that tension increased sig-

nificantly on the shorter 'time sets' and that the decrement was less per unit of time on the shorter 'sets' than upon the longer ones. If there is a relation between tension and the difficulty of the task, and data to be presented subsequently indicate that there may be, it is legitimate to assume that it is obscured in this experiment by changes in tension on successive trials.

The phenomenon of variability is studied in relation to several phases of this general problem. However, no very great significance is attached to this feature of the study. From the nature of the case one might expect greater variability on the difficult mazes. There are more 'cul de sacs' in the difficult mazes. The subjects had a tendency to move in strokes, as it were. One unit (one 'cul de sac' or one alley) constituted a convenient stroke. The movement spans are shorter on the difficult mazes since they have more 'cul de sacs' and are cut up into shorter units. These movement units give tension curves which have rhythmical appearance. The rhythms on the more difficult mazes are more frequent and give more variable curves.

(c) *Tension for Trials in Which the Greatest Number of Errors was Made Versus That for the Trials in Which the Least Number of Errors was Made.*—In the case of mazes CIII, CIV and III, the average tension on the four trials in the first half of each record with the most errors is compared with the average tension on the four trials in the same section of the records with the fewest errors. In the case of maze CII the average tension of the two trials among the first six with the greatest number of errors is compared with the average tension of the two trials among the first six with the smallest number of errors. A special treatment of the data for maze CIII is given after the maze designated CIII'. The treatment represents an attempt to control the effect of a general decrease in tension with progress in learning. The decrease in the case of this maze, the most difficult of all, is especially pronounced. In the case in question two consecutive trials were selected for comparative purposes in which there was a difference of 10 or more in errors made on the two trials and in which case the

trial with the fewest errors came first. The first and second pairs of trials meeting this requirement were chosen.

TABLE III

SHOWING THE RELATION BETWEEN TENSION ON TRIALS WITH THE GREATEST NUMBER OF ERRORS AND THAT ON TRIALS WITH THE LEAST NUMBER OF ERRORS

Maze	Category	Tension	Difference in Means	P.E. (of Diff.)
CIII	Most Er's.....	.208 inch		
CIII	Fewest Er's.....	.161 inch	.048	$\pm .014$
CIV	Most Er's.....	.336 inch		
CIV	Fewest Er's.....	.298 inch	.038	$\pm .036$
III	Most Er's.....	.326 inch		
III	Fewest Er's.....	.298 inch	.038	$\pm .021$
CII	Most Er's.....	.275 inch		
CII	Fewest Er's.....	.233 inch	.042	$\pm .038$
CIII'	Most Er's.....	.193 inch		
CIII'	Fewest Er's.....	.165 inch	.028	$\pm .020$

These data show a consistent, but not individually statistically significant positive relationship between the tension expressed per trial and the number of errors made per trial. These differences obtained are fairly large and all point in the same direction. This may be suggestive of a tendency. However, the general level of tension varied greatly from subject to subject. This factor doubtless operates to give high probable errors. It seems legitimate to assume, in the light of this tendency, that the trials which are most difficult for a subject are those in which he makes the most errors and that the trials which are the easiest for him are those in which he makes the fewest errors. If this is a valid assumption, these data indicate the possibility of a direct relationship between tension and the difficulty of the task.

(d) *Variations in Tension with Progress in Learning.*—Tension was computed for four samples of three trials each at four different stages in the learning process. The average tension was determined for the first three trials, the middle three, the last three and the three trials immediately preceding them. These constitute the four stages.

These figures possess considerable significance for this

TABLE IV
SHOWING CHANGES IN TENSION WITH PROGRESS IN LEARNING

Maze	Stage 1	Stage 2	Stage 3	Stage 4
CII	.268 inch	.303 inch	.355 inch	.359 inch
CIII	.260 inch	.186 inch	.230 inch	.209 inch
CIV	.338 inch	.323 inch	.307 inch	.279 inch
IV	.323 inch	.368 inch	.468 inch	.472 inch
III	.333 inch	.326 inch	.309 inch	.315 inch

general problem. In the case of the more difficult mazes, CIII, CIV and III, there is present a somewhat general decrease in tension as learning progresses. The decrease in tension on maze III is not as pronounced as that on CIII or CIV. It will be recalled that one half of the subjects learned this maze under induced tension. One of the effects of induced tension was to keep tension relatively high throughout all stages in learning. It seems reasonable to suppose that the decrease in tension on these mazes may be due in part, at least, to an increase in familiarity with the mazes. Another possible factor contributing to the decrease in tension is that of a general work decrement. In the case of maze III, on which maze the decrease in tension is greatest, the average time required to learn was 2671 seconds. The average time required to master CIV was 2043 seconds and that for III was 1543 seconds. It will be observed that the decrease in tension is somewhat proportional to the length of time required to master the mazes.

Mazes CII and IV present quite a different picture. Here, it will be observed, tension increases throughout the stages in learning. The learning times for these two mazes are extremely short when compared with that for the other three mazes. The average number of seconds required to learn maze CII was 354, and that required to learn IV was 563. The subjects never acquired as great a degree of familiarity with these two mazes as they did with the other three. In learning the more difficult mazes the subjects explored every part of them over and over again. In the easier mazes certain portions were explored rarely or not at all by many subjects. Furthermore, it seems likely (as suggested above) that the

subjects, when they discovered that they were confronted with an easy task, put forth an increased effort to terminate it as quickly as possible in order to make a good score. It will be observed that the initial tension on the easy and difficult mazes, when learned by the same subjects, is not essentially different.

(e) *The Phenomena of Initial Changes in Tension.*

TABLE V

SHOWING THE AVERAGE TENSION PER TRIAL FOR EACH OF THE FIRST THREE TRIALS

Maze	Trial 1	Trial 2	Trial 3
CIII	.311 inch	.248 inch	.251 inch
CII	.288 inch	.296 inch	.301 inch

There is an enormous difference in the difficulty of these two mazes, CIII being several times as difficult as CII. It seems that the differences in the direction of the initial changes in tension on these two mazes may be interpreted in the light of their difficulty. One might assume that the initial high level of tension followed by a drop, in the case of maze CIII, points to the initial spurt phenomenon and, indeed, suggests an interpretation of the initial high level of efficiency in terms of an initial high level of muscular tension. The time required for the first tracing was usually quite long. The subject may realize that he is confronted with a lengthy task and may settle down to a slower pace as it were. On the contrary, in the case of maze CII, the subject may realize from his early experience with the maze that he is confronted with an easy task and therewith increase his effort with successive trials.

TABLE VI

SHOWING THE CHANGES IN TENSION OVER SIX INTERVALS OF 10 SECONDS EACH, REPRESENTING THE FIRST MINUTE OF LEARNING TIME

Maze	Interval					
	1	2	3	4	5	6
III	.34	.43	.43	.44	.43	.39
CIII	.33	.40	.34	.32	.29	.28

Tension is given in this table in terms of hundredths of an inch. In the subsequent table a similar study is made which embraces the first minute of tracing of each of the first four trials of 24 records selected at random, save for the fact that no record was chosen for this purpose which showed no appreciable tension. This would account for the fact that the tension values are abnormally high when compared with the average of the tension of the whole of the records.

TABLE VII

SHOWING THE CHANGES IN TENSION OVER SIX INTERVALS OF 10 SECONDS EACH, REPRESENTING THE FIRST MINUTE OF LEARNING TIME ON EACH OF THE FIRST FOUR TRIALS

Trial	Interval					
	1	2	3	4	5	6
1.	.24	.28	.30	.35	.37	.36
2.	.31	.43	.50	.50	.52	.50
3.	.24	.38	.46	.52	.54	.54
4.	.26	.41	.50	.57	.55	.56

Tension is recorded in terms of hundredths of an inch. The data presented in the two preceding tables indicate that a few seconds are required in each trial for establishing a motor set.

(f) *The Phenomena of Final Changes in Tension.*—Tension values are averaged for each of the last three trials for all subjects on three mazes. The criterion of learning in all cases was three consecutive errorless trials. Hence the three trials considered in this connection are necessarily trials without errors. The subjects were all informed of this criterion. The average time required for tracing each of these three trials is given together with the tension values in the following table as an aid in interpreting the results.

These results show increase in tension on the last trial over the preceding trial. They seem to indicate rather convincingly that changes in tension are to be regarded, in part at least, as expressions of changes in effort. This interpretation of the results is substantiated by the corresponding time

TABLE VIII

SHOWING CHANGES IN TENSION AND TIME VALUES OVER THE LAST THREE TRIALS

Maze	Trial	Tension	Time
CII	Last but two.....	.333 inch	21.1 seconds
CII	Last but one.....	.353 inch	19.8 seconds
CII	Last.....	.358 inch	20.3 seconds
CIII	Last but two.....	.187 inch	27.9 seconds
CIII	Last but one.....	.194 inch	27.1 seconds
CIII	Last.....	.257 inch	29.7 seconds
III	Last but two.....	.346 inch	22.6 seconds
III	Last but one.....	.316 inch	22.1 seconds
III	Last.....	.362 inch	22.7 seconds

changes. The reader will observe by inspecting the above table that there is an increase in time required to trace the mazes on the last trial. This would indicate that the subject proceeds more cautiously—that he is making a greater effort to trace the mazes correctly. The subject is aware that making an error on this trial means that he must start over in his effort to achieve three consecutive errorless trials, which fact would add at least three trials to his score.

PART II. THE RELATION BETWEEN TENSION AND THE SPEED OF LEARNING

The records of the various subjects on all the mazes are ranked according to tension on their respective mazes. These individual records are divided into two groups on the basis of tension. The category marked *A* contains the 50 percent of the records showing the greatest degree of tension. That designated *B* contains the 50 percent of records showing the lowest degree of tension. The P.E. of the difference between the means is given for all comparisons.

All the differences for maze CII are more than three times their probable errors. On maze CIII the difference between the means for time is 2.5 times its P.E., and for errors is 4.4. times its P.E., and for trials, is about equal its P.E. It is apparent that there is a consistent and significant relation between tension and speed of learning for mazes CII and CIII. It is equally apparent that no striking or uniform tendency is present in the case of the other three mazes. As a partial

explanation of this disturbing factor the reader's attention is called to the fact that all the subjects for mazes CII and CIII were without prior experience with mazes. They were, for the most part, sophomores and juniors taking their first courses in psychology. The subjects for the other mazes

TABLE IX
SHOWING THE RELATION BETWEEN TENSION AND THE SPEED OF LEARNING

Maze	Category	Average Seconds	Average Errors	Average Trials
CII	A	222	8.3	8.5
CII	B	485 $\pm$ 76.00	33.0 $\pm$ 6.50	12.1 $\pm$.98
CIII	A	2426	321	40.9
CIII	B	2916 $\pm$ 205.31	527 $\pm$ 46.50	48.9 $\pm$ 7.80
CIV	A	2027	265	25.7
CIV	B	2059 $\pm$ 295.64	227 $\pm$ 45.53	28.0 $\pm$ 5.40
IV	A	520	81	14.3
IV	B	606 $\pm$ 87.00	83 $\pm$ 14.75	14.1 $\pm$ 1.55
III	A	1638	244	31.9
III	B	1447 $\pm$ 207.25	197 $\pm$ 41.25	27.7 $\pm$ 3.5

constituted a more variable group, ranging all the way from advanced graduate students in psychology to undergraduates with very little training in this subject. The members of this group possessed varying degrees of maze experience. Some of the subjects were to some degree familiar with all the mazes in the laboratory; others had had a moderate amount of contact with mazes and others had had no experience with them. The reader will bear in mind that each maze group was selected for the study of a particular phenomenon such, for example, as the effect of induced tension upon the speed of learning. In such cases pairs of mazes were used. Care was taken to see that a subject had previously learned both mazes of a given pair in case he had learned one of them. It seems that this factor of variable experience might be sufficient to cut across and tend to interrupt any other tendency which one might be studying. Former experience might well be an aid in some cases and a hindrance in others. It might change the experimental attitudes of the subjects and their tension records in a complex set up such as this in various ways. A test of this assumption is possible to some extent. It happens that 15 of the 32 subjects used in mazes III and IV were without

previous contact with mazes. When the records of these 15 subjects are ranked according to tension the results are in accord with those for mazes CII and CIII as shown in Table IX above. The results of this feature are given in Table X.

TABLE X
SHOWING THE RELATION BETWEEN TENSION AND SPEED OF LEARNING FOR 15 SUBJECTS
WITHOUT PRIOR EXPERIENCE

Maze	Category	Average Seconds	Average Errors	Average Trials
III	A	1102	164	29
III	B	2067 $\pm$ 306.00	312 $\pm$ 68.27	42 $\pm$ 6.20
IV	A	485	72	17.2
IV	B	630 $\pm$ 68.25	100 $\pm$ 13.01	15.6 $\pm$ 3.50

These results lend weight to the assumption made above relative to the detrimental influence of the variable factor of previous experience upon the relation between tension and the speed of learning. The final conclusion regarding this relationship must rest to a large degree upon the validity of this assumption. If the assumption is valid the conclusion would follow that there is evidence of a significant relationship between muscle tensions as measured in these experiments and the speed of learning material of this kind.

PART III. THE EFFECT OF INDUCED TENSION

In this part of the study the results of the various observations upon the influence of induced tension are given. The reader will recall that tension was induced artificially by having the subjects hold a weight with a static pull of 14 pounds against a pulley. In all these calculations the results in category *A* represent those in which the subjects were under the influence of induced tension. In category *B* the results are given for normal conditions.

TABLE XI
SHOWING THE INFLUENCE OF ARTIFICIALLY INDUCED TENSION UPON THE TENSION
EXPRESSED UPON THE KYMOGRAPHIC DRUM

Maze	Category	Average Tension
III.....	A	.369 inches
III.....	B	.268 inches $\pm$.043
IV.....	A	.364 inches
IV.....	B	.306 inches $\pm$.044

These results show that artificially induced tension has a tendency to increase the expression of tension on the kymographic drum. This fact would seem to suggest that increasing the tension in one or more muscle groups tends to increase the tension in all other groups. This is in agreement with the fact that there is a significant positive correlation between the various indices of muscular tension employed in this study. It is also in accord with the well-known fact that induced tension in any muscle groups of the body heightens the knee jerk.

TABLE XII

SHOWING THE EFFECT OF ARTIFICIALLY INDUCED TENSION UPON THE CONSTANCY OF TENSION EXPRESSED ON THE DRUM THROUGHOUT THE STAGES OF LEARNING

Maze	Category ⁴	Stage 1	Stage 2	Stage 3	Stage 4
III	A. Tension in inches.....	.347	.390	.378	.405
III	B. Tension in inches.....	.319	.262	.240	.225
IV	A. Tension in inches.....	.421	.472	.481	.494
IV	B. Tension in inches.....	.225	.264	.375	.454

⁴ In category *A* are found the tension values for the condition of induced tension; in *B* those are found for the condition in which tension is not artificially induced.

These results show that induced tension has the effect of stabilizing the motor attitude of the subjects during the learning process. They also show that induced tension has the effect of producing relatively high initial tension and that this initial high level of tension is not only maintained throughout the four stages of learning studied but that the level of tension increases regularly from stage to stage. The results for maze III present a particularly interesting picture in this connection. It will be observed that for the condition without induced tension the tension values decrease from beginning to end, as indeed they do on all the longer mazes in which tension is not artificially induced. On this same maze, however, it will be observed that tension increases regularly to the end of the learning period when induced tension is used. As noted earlier, tension on mazes CII and IV, short easy mazes, increases regularly from beginning to end under all conditions. In maze IV of the table above it is interesting to observe the extremely high initial tension for the condition with induced

tension, as compared with that for the condition without induced tension.

These facts seem to tie up with some of the earlier findings. For example, if we were correct in interpreting the expression of increasing tension on the two easy mazes as indicative of increasing effort, then it would seem that the effects of induced tension could be interpreted, in part at least, as producing an effect equivalent to increased effort. Indeed these findings may be interpreted as throwing light upon the nature of effort. In the light of this interpretation muscular tensions would be regarded as one of the important components of effort.

TABLE XIII

SHOWING THE EFFECT OF INDUCED TENSION UPON THE RATE OF LEARNING

Maze	Category	Average Seconds	Average Errors	Average Trials
III	A	1133	158	25.8
III	B	1954 $\pm$ 207.84	286 $\pm$ 40.62	34.3 $\pm$ 4.12
IV	A	469	68	14.3
IV	B	657 $\pm$ 83.07	94 $\pm$ 15.00	14.1 $\pm$ 4.30

In the case of maze III the mean difference between the two conditions, tension and normal, for time is approximately four times the probable error, for errors is three times the probable error, and for trials is approximately twice the probable error. The benefits resulting from tension are less marked on maze IV. The differences are about twice their probable errors for time and errors. Practically no difference exists in the case of trials. The difference in the degree to which the data for these two mazes reveal benefits from induced tension possesses considerable significance for this general problem. Inspection of Table XI reveals that the increase in tension, as expressed on the drum, because of induced tension, was little more than half as much in the case of maze IV as in the case of maze III. It was pointed out earlier that there is a marked tendency for tension to increase on mazes IV and CII, the easy mazes, with successive trials. This was interpreted as meaning that the subjects put forth and increased effort when they discovered that they were

confronted with a task likely to be terminated in a reasonably short time. As mentioned earlier, this interpretation seems to have experimental justification. In the light of the differences to which these mazes show benefits of induced tension it is suggested that there is a possibility that induced tension is more efficacious on longer than on shorter tasks.

Hunter and his students, for example Heron (5), have shown that maze scores are only moderately reliable. In view of this fact these results are strongly suggestive of genuine facilitation of learning by induced tension. Apparently there may be several factors which influence the speed of learning. Some of these have been insufficiently studied. Doubtless subjects differ in the amount and kind of imagery used, in tendencies to verbalize, in the size of the muscle groups employed in tracing the mazes, in tendencies to retrace, methods of exploration, perseverative tendencies, and in many other ways. These factors, when uncontrolled, as was the case in these experiments, may contribute to unreliability. In view of these possibilities it seems rather significant that the speed of learning mazes can be influenced in a manner even moderately significant statistically by the introduction of a single factor, muscular tension. Despite the fact that all the results obtained in this study are not statistically significant considerably importance may be attached to the fact that practically all the results point in the same direction and that they compose with the main body of facts derived in this study.

It is difficult to see how mere chance selection could give these results. A fairly large number of subjects was employed (32). Each subject learned both mazes, one under induced tension, the other under normal conditions. The obtained results show that the same subjects who learned one of the mazes most quickly under the influence of induced tension were the subjects who proved to be the poorest learners on the other maze under normal conditions.

The objection may be offered that muscle tensions, as induced in this experiment, are of no very great service *per se*; but that on the contrary the increased efficiency comes from a

redoubled effort to overcome the effects of distraction or to terminate the task made disagreeable by holding the weight. Several objections may be offered to this point of view. In Bills' study, cited above, the same subjects worked under the same conditions for a number of days. He suggests that if the advantage of muscular tension were due merely to the distracting influence of the method of inducing the tension the subjects ought to become habituated to the distracting influence of the inducing agent and cease to show benefits from it. On the contrary he found that the beneficial influence increased with practice. It seems likely that overcoming distracting influences by increasing effort is a similar thing to the condition involved in increasing muscular tension. Morgan (12) has shown that the process of overcoming distraction is accompanied by increased muscle tension. That these muscle tensions serve a useful purpose is suggested by the fact that the results of the present study indicate that there is a positive relation between the expression of these tensions and the speed of learning. The data presented in part I of this study, relative to initial spurt, end spurt, and the relation of tension to the length and difficulty of the task, seem to indicate that there exists an essential relationship between muscular tensions and effort. Bills and Brown (2) in their studies on the influence of 'quantitative set' found the decrement significantly less on the smaller 'amount sets' than on the larger ones, amount set being determined by a knowledge on the part of the subject of amount of work to be done. Not only was the decrement less for the shorter sets, but also muscular tension increased significantly during the performance of the shorter tasks. These results are supported by the findings presented in part I of this study relative to the high level and constant increase of tension on the two short mazes as opposed to a lower level and a decrease of tension on the longer mazes. On the bases of these considerations the suggestion is offered that increases in muscular tensions have an effect equivalent to increases in effort.

In these experiments few subjects showed any signs of strain from holding the weight. Only two stated that the

weight seemed to distract or bother them. The subjects usually stated that they 'ignored' or 'forgot about' the weight while tracing the mazes.

RELATION BETWEEN THE THREE INDICES OF MUSCLE TENSION

The following table shows the correlation, first, between downward pressure and horizontal pressure or grip, second, between downward pressure and jaw tension, and third, between horizontal pressure and jaw tension. The correlations were computed between the respective tension values for 300 trials selected at random.

TABLE XIV
SHOWING THE RELATION BETWEEN THREE MEASURES OF MUSCLE TENSION

First Variable	Second Variable	Correlation
Downward pressure.....	Horizontal pressure	$r \ .67 \pm .02$
Downward pressure.....	Jaw tension	$r \ .44 \pm .03$
Horizontal pressure.....	Jaw tension	$r \ .33 \pm .03$

The correlation between downward and horizontal pressure seems rather high in the light of the apparent unreliability of the measure of horizontal pressure. It is difficult to form a judgment as to what extent this correlation represents a genuine relation between the tension of two muscle groups. It is doubtless influenced to some extent by the fact that it would be necessary to grip the stylus to some extent in order to exert downward pressure upon it. On the other hand one might expect to find considerable correlation between two expressions of tension of muscles involved in the same act and involving to some extent the same muscles. It will be observed that the correlations are much lower, but significant, between downward and horizontal pressure and jaw tension. This difference may be due, in part at least, to a greater relation between the tension of muscle groups involved directly in the performance of an act than between that of muscle groups not so involved. It may well be that muscle tension is greater in general among muscles active in the performance of a certain act than among those not directly involved in the act. Even though muscle tension was present in the jaw muscles every time it was present in the muscles involved in

manipulating the stylus it would not necessarily follow that such tension would express itself by pressing the teeth together. The subject might well extend his jaw or twist it to one side, which fact would hardly be recorded on the drum. If the subjects had been given something to bite upon or hold between their teeth probably better results would have been obtained from this feature.

GENERAL SUMMARY

1. There seems to be a consistent positive relation between tension and the difficulty of the task. The chief source of evidence for this statement is derived from the fact that tension on the trials with the greatest number of errors is greater than that on the trials with the fewest errors. The differences are consistent in that they all point in the same direction, although most of them are not statistically significant.

2. Significant changes in tension occur with progress in learning.

(a) Tension decreases somewhat regularly with successive trials on the longer and more difficult mazes. The decrease is directly proportional to the length of time required to learn the mazes.

(b) Tension increases with successive trials on the easy mazes. These results signify a relation between muscular tension and mental set.

(c) Tension for the last trial is greater, on an average, than that for the preceding trial. The time required to trace the last trial is greater than that on the preceding trial. These concomitant phenomena are interpreted to mean an increased effort to trace the last trial correctly (three consecutive correct trials constituted the criterion of learning). These findings are regarded as throwing light upon the phenomenon of end spurt.

3. There is considerable evidence that a positive relation obtains between tension and the speed of learning. The results for the subjects naïve with respect to maze learning point unmistakably toward this conclusion. The results for the sophisticated subjects show no consistent tendency.

4. The tension in the hand operating the stylus is increased by the artificially induced tension in the other hand. Inducing tension artificially has the effect of producing relatively high initial tension and enhancing the tension throughout the stages in learning; whereas tension under normal conditions decreases on all the longer mazes during progress in learning.

5. The rate of learning is materially affected in a positive way by artificially inducing muscular tensions. The improvement obtains in five of the six comparisons.

6. On the basis of a fairly consistent interplay of phenomena revealed by the foregoing experiments the conclusion is drawn that there is an increase in muscular tensions during effortful activity and that these tensions are valuable in activity of the kind involved in learning mazes.

INTERPRETATION

The foregoing results seem to be best interpreted in the light of the phenomenon of 'facilitation.' Several examples of this phenomenon are found in psychological literature as well as in everyday observation. Simple demonstrations can be had by holding the breath for a relatively long period and observing the increasing tenseness of various muscle groups. Similar observations may be made from exerting maximum squeeze upon a dynamometer, or from maintaining the arm in an extended horizontal position to the point that it requires extreme exertion. These 'extra' muscular tensions seem to be of assistance in executing effortful acts of this kind. Bills has aptly applied the term 'remote controls' to this phenomenon. In the experimental literature one meets the fact that reflex activity is enhanced by inducing tension in muscles not directly involved in the performance of the act. Miller has shown, as cited earlier, that the liveliness of a sensory experience resulting from electrical stimulation, as well as the motor response thereto, is greatly diminished by 'progressive relaxation.' Fere (4) has demonstrated that muscular contractions are concomitants of attentive processes. It has been well demonstrated, particularly by Todd (13), that reaction time to two sensory stimuli is quicker than that to either

one alone and that to three quicker than that to two. The most adequate neurological explanation of this psychological phenomenon seems to be that of 'facilitation' by summation of nervous impulses having different sensory origins. By means of a final common path stimuli arising from different receptors may produce a single response which may, because of the summation of impulses, be quickened and strengthened — 'facilitated.' The suggestion is made that in this same sense the impulses arising from sense organs lodged in muscles and tendons, owing to stimulation by muscular contractions, may re-enforce the impulses aroused by the dominant stimulus and aid in the production of the response.

REFERENCES

1. BILLS, The influence of muscular tension on the efficiency of mental work, *Amer. J. Psychol.*, 1927, **38**, 227.
2. BILLS AND BROWN, Quantitative set, *J. Exper. Psychol.*, 1929, **12**, 301.
3. DRESSLER, Some influences which affect the rapidity of voluntary movement, *Amer. J. Psychol.*, 1891, **4**.
4. FERE, *Sensation et Mouvement*, 1889.
5. HERON, Individual differences in ability versus chance in learning stylus maze, *Comp. Psychol. Monog.*, **2**.
6. JACOBSON, Further experiments on the inhibition of sensations, *Amer. J. Psychol.*, 1912, **23**, 345.
7. —, Progressive relaxation, *Amer. J. Psychol.*, 1925, **36**, 73.
8. —, *Progressive Relaxation*, 1929.
9. LAIRD, Experiments on the physiological cost of noise, *J. Nat. Inst. Indus. Psychol.*, 1929, **14**, 254-258.
10. LOMBARD, The variations in the normal knee jerk, and their relation to the activity of the central nervous system, *Amer. J. Psychol.*, 1887, **1**, 71.
11. MILLER, Changes in response to electric shock produced by varying muscular conditions, *J. Exper. Psychol.*, 1926, **9**, 26.
12. MORGAN, The overcoming of distraction and other resistances, *Arch. Psychol.*, 1916, **35**, 1.
13. TODD, Reaction time to multiple stimuli, *Arch. Psychol.*, 1912, **21**.
14. TUTTLE, Effect of attention or mental activity upon patellar tendon reflex, *J. Exper. Psychol.*, 1924, **7**, 401.
15. —, The distribution of tone in skeletal muscle, *J. Exper. Psychol.*, 1925, **8**, 319.
16. WASHBURN, *Movement and Mental Imagery*, 1916.
17. YOUNG, P. T., The phenomena of organic set, *Psychol. Rev.*, 1925, 319.

(Manuscript received October 27, 1930)

LANCASTER PRESS, INC.
LANCASTER, PA.